III. *A Letter to the Right Honourable the Earl of* Morton, *Preſident of the Royal Society. Containing Experiments and Obſervations on the Agreement between the Specific Gravities of the ſeveral Metals, and their Colours when united to Glaſs, as well as thoſe of their other Proportions: By* Edward Delaval, *F. R. S. M. A. and Fellow of* Pembroke Hall, Cambridge.

My Lord,

Read Jan. 24, 1765.

I TAKE the liberty of laying before your Lordſhip the following paper, containing a variety of facts and experiments, which I have endeavoured to apply to ſome Optical inquiries.

Beſides the experiments originally contrived and made by myſelf, I have repeated moſt of thoſe which I have quoted from others.

Sir Iſaac Newton, in his Optics, has ſhewn by a ſeries of experiments, that the ſeveral differences of colours, exhibited by thin tranſparent plates, are occaſioned by their ſeveral thickneſſes; and that therefore the tranſparent parts of bodies do, according to their different ſizes, reflect rays of one colour and tranſmit thoſe of another; and conſequently that the bigneſs of the component particles of natural bodies may be conjectured from their colours; ſince the particles of thoſe bodies moſt probably exhibit the ſame colours as a plate of

of equal thickneſs, provided they have the ſame denſity. He concludes this whole doctrine in theſe words: "I have hitherto explained the powers of "bodies to reflect and refract, and ſhewed that "thin tranſparent plates, fibres, and particles, do, "according to their ſeveral *thickneſſes* and *denſities*, "reflect ſeveral ſorts of rays, and thereby appear "of ſeveral *colours*; and by conſequence, that no-"thing more is requiſite, for producing all the "*colours* of natural bodies, than the ſeveral *ſizes* "and *denſities* of their tranſparent particles."

Though he has accurately ſhewn what *colours* ariſe from the ſeveral changes of *thickneſs*, I do not find that any one has attempted to explain *in what manner* the differences of *denſity*, in the component particles of bodies, contribute to produce the ſeveral differences of *colours*: and therefore I thought, that if inſtances could be produced of bodies whoſe ſeveral differences of *colour* appear to be proportioned to their ſeveral degrees of *denſity*, it would tend to illuſtrate this part of Optics.

To this purpoſe, however, are conducive all thoſe experiments and obſervations, from which Sir Iſaac Newton has inferred that bodies have their *refractive and reflective powers* nearly proportional to their *denſities*; and that the *leaſt refrangible* rays require the *greateſt* power to reflect them: which is deducible from hence, 1. that the *red* rays are reflected at the *greateſt* obliquity of incidence, and the *violet* at the *leaſt*, 2. that the *violet* is reflected, in like circumſtances, at the *leaſt* thickneſs of any thin plate or bubble, the *red* at the *greateſt* thickneſs, and the intermediate colours at intermediate

thickneſſes. 3. The ſame appears from the table (p. 206.) in which the thickneſſes of air, water, and glaſs, and the colours produced by them are ſet down.

Theſe experiments are applied by him to tranſparent bodies and the colours exhibited by them; but they are equally applicable to permanently coloured bodies: and it appears from them, that *denſer* ſubſtances ought, by their *greater reflective power*, in like circumſtances, to reflect the *leſs refrangible* rays, and that ſubſtances of *leſs denſity* ſhould reflect rays proportionably *more refrangible*, and thereby appear of ſeveral colours in the order of their denſity.

In confirmation of this reaſoning, I ſhall give inſtances of natural bodies, which differ from each other in *denſity*, though circumſtanced alike in other reſpects; and ſhall ſhew that they differ in *colour*, in the ſame order they do in *denſity*, the *denſeſt* being *red*, the next in *denſity orange*, *yellow*, &c.

In ſuch an inquiry metallic bodies ſeem to deſerve our firſt and principal attention, as their *ſpecific gravities* have been aſcertained by well known and repeated experiments. Without entering into a minute chemical theory of the principles of metals, it is ſufficient to obſerve that they are univerſally allowed to conſiſt of 1. an inflammable or ſulphureous matter, which is of the ſame kind in all the metals; 2. of a fixed matter or calx, which appears in each of the metals to be ſpecifically different in *weight*, as well as in other properties.

As the ſulphureous matter, in the intire metals, acts ſtrongly on the rays of light, it is neceſſary to calcine, or to divide them into extremely minute particles, in order to examine ſeparately the action of the calx, or fixed matter, on the rays of light.

In order to examine all the metals in like circumſtances, by reducing them into the ſmalleſt particles, and depriving them of their ſulphur as far as was practicable, I expoſed each of them, united with a proper quantity of the pureſt glaſs, *without any additional ingredient, to the greateſt degree of fire* they are capable of bearing, *without having all colour whatever deſtroyed.*

In this ſtate it appears, from a variety of experiments and facts, that they actually do, without any exception, exhibit colours in the order of their denſities, as follows,

Gold ——— Red.
Lead ——— Orange.
Silver ——— Yellow.
Copper —— Green.
Iron ——— Blue.

GOLD.

GOLD.

GOLD, which is the denſeſt of all the metals, imparts a red colour to *glaſs*, whenever it is divided into particles ſo minute, that it can be intimately mixed with the ingredients of which the glaſs is made; and it ſeems indifferent in what manner it is reduced to this ſtate. Thus

1. From the powder obtained by rubbing *gold* with a pumice ſtone, uſed by the goldſmiths in poliſhing it, mixed with nitre, borax, and potaſh, a beautiful *red* glaſs is produced [*a*].
2. When a ſmall quantity of a ſolution of *gold* in aqua regia is evaporated on a *glaſs* plate, with a gentle heat, that part of the *glaſs* on which it lay thinneſt, is tinged *red*, by the entrance of the particles of *gold* into it's ſurface [*b*].
3. Artificial rubies are made by mixing with *glaſs*, *gold* diſſolved in aqua regia, and afterwards calcined in the furnace [*c*].

[*a*] Sol ſine veſte, cap. 8.

Junker, Conſpectus Chem. tab. XXXIII. de Auro, p. 852.

Aurum detritum pumice, ſeu pulvis auri pumice, quo aurifabri ſua opera poliunt et abradunt, commiſtus, Gold-Schliff, ſi cum ana nitri, boracis, et cinerum clavellatorum liquido fundatur, præbet *vitrum*, inſtar optimi opificum encauſtici, *rubro colore* pellucidum, ſubſidentibus paucis auri granulis; teſtante autore Solis ſine veſte.

Shaw on Boerhaave's Chem. vol. i. p. 79. *Gold* ground with pumice, and afterwards fuſed with equal parts of nitre, borax, and pot aſhes, affords a fine tranſparent *red glaſs*.

[*b*] Philoſ. Tranſ. N°. 286.

[*c*] Neri's art of Glaſs, chap. 129.

Calcine *Gold* with aqua regia many times, pouring the water upon it five or ſix times: then put this powder of Gold in

4. Kunkel

4. Kunkel prepared a powder for the ſame purpoſe, by precipitating the *gold* from the ſolution by an alkaline liquor [*d*].
5. *Gold* precipitated by tin from aqua regia, and melted with *glaſs* in a proper proportion, tinges it with a beautiful ruby colour: this method was diſcovered by Caſſius [*e*], and farther improved by Kunkel [*f*].
6. The ſame colour is produced by fuſing *gold* with a large proportion of tin, and two thirds of lead, or by mixing it with regulus of antimony, or tin by calcination, and adding to *glaſs* the powders of *gold* obtained from theſe proceſſes [*g*].
7. *Gold* amalgamated with mercury, and digeſted with it for a conſiderable time, may be reduced to a ſubtile powder by expelling the mercury: this powder, melted into the *glaſs*, tinges it of a *beautiful red* [*h*].

earthen pans, to calcine in the furnace, till it becomes a *red* powder; which will be in many days; then this powder, added in ſufficient quantity, and by little and little, to *fine cryſtal glaſs*, which has been often caſt into water, will make the tranſparent *red of a ruby*, as by experience is found.

[*d*] Lewis's Hiſtory of Gold, p. 176.

[*e*] Caſſius de Auro, p. 105.

[*f*] Junker, Conſp. Chem. tab. XXXIII. de Auro, p. 861.

[*g*] Shaw's Notes on Boerhaave's Chem. vol. i. p. 78.

[*h*] Shaw's Abridgement of Boyle, vol. i. p. 459.

An induſtrious perſon, having united *Gold* with a particular quickſilver, kept them in digeſtion for ſome months; when the fire having been immoderately increaſed, the ſealed glaſs burſt with a frightful noiſe: though the upper parts were blown off and ſhattered to pieces, yet the lower eſcaped tolerably whole; and I took notice, with delight, that it was tinged throughout of a *fine and glorious red*, hardly to be matched by that of *Rubies*.

8. *Gold*

8. *Gold leaf* melted into the surface of *glass*, by the electric force, imparts a *red colour* to it: this was first observed by Dr. Franklyn, and has been often repeated [*i*].

There are many other ways of communicating this *colour to glass* by *Gold*; and I find no method by which it can be made to produce any other colour. If it be mixed in larger masses, without being minutely divided, it imparts no colour to the glass, but remains in its metallic form.

Grummet attributes this colour to the manganese, used in making some sorts of glass, the colour of which he supposes revivified by the nitre used in the preparation of the gold: it is necessary therefore to mention, that I have given a *red* by *gold* to several *glasses*, in the composition of which there was *no manganese*, and often by gold in the preparation of which there was *no nitre*.

Several preparations of *gold* will impart *a fine red* to the fritt or materials of which glass is made, in a small degree of heat; though not minutely enough divided, or in too large quantity, to remain mixed with the glass, when exposed to a degree of heat sufficient to vitrify them perfectly.

[*i*] Franklyn's Letters on Electricity, p. 65.

LEAD.

LEAD.

LEAD, which is the metal whose *density* is next in order to that of gold, affords a glass of the colour of the Hyacinth, a gem whose distinguishing character is, that it is *red* with an admixture of *yellow*, the same colour which by writers in optics is called *orange*.

1. Lead, kept in fusion for a considerable time, in a strong crucible and a very violent heat, is reduced to a glass of the colour of that gem [*k*].
2. Lead reduced to litharge, and melted with one third or fourth part of it's weight of sand, in a covered crucible, in a strong fire for two or three hours, unites with the sand into an *orange-coloured glass* like the former [*l*].
3. *Glass of Lead* is mentioned by several authors, as a composition proper, without the addition of any other ingredient, for imitating the *Hyacinth* [*m*].

[*k*] Flora Saturnizans, chap. 11. Henckel de appropriatione, cap. ii. sect. 4.

[*l*] Junker, Conspect. Chem. tab. XIX. p. 434.

Recipe Lithargyrii partes tres, arenæ nitidæ partem unam; mista imponantur forti tigillo; per 3 circiter horas tenuissime fundantur, quo facto massam fluentem in calidum mortarium effunde, et habebis *vitrum* pellucidum, *Hyacinthini ferme coloris.*

[*m*] Shaw's Lectures, p. 299.

Lead melted into glass with sand is the foundation of imitating all the coloured gems: for this glass itself will resemble the Hyacinth, &c.

Merret's Notes to Neri, chap. 61.

Our author mentions not a *Hyacinth* from *glass of Lead.* Bap. Porta supplies you with it, l. vi. c. 7. in these words: To make

SILVER.

YELLOW is the only colour which *ſilver*, the metal next to lead in *denſity*, can by any preparation be made to impart to *glaſs*.

1. Without inſiſting upon what ſome chymiſts affirm, that *ſilver*, on being calcined and expoſed to a violent fire for a long time, was partly reduced to a *yellow glaſs* [*n*],
2. I have often given *that colour*, by moiſtening the ſurface of the *glaſs* with a *ſolution of Silver*, and afterwards making it red hot.
3. If *Silver* be calcined with ſulphur, it readily communicates a *yellow colour* to glaſs [*o*].

a very *Hyacinth*, and not much differing from the true one, put *lead* into earthen pots that are very hard, in a glaſs furnace, and there let it ſtand ſome days, and thus your *lead* is turned into *glaſs*, and imitates the *colour of the Hyacinth*.

Nichols's Hiſtory of precious ſtones, part i. chap. 7. of the Hyacinth.

The Hyacinth is a ſtone (as ſaith Boetius and Rulandus) which is *red* with a certain *yellowneſs*, or *rufeſcit in auro*; that is, it is *red* in *yellow*. Impoſtors adulterate it with a kind of *glaſs made of Lead*.

Boetii gemmarum et lapidum hiſtoria, l. ii. c. 31. Adulterium *Hyacinthi* vix meretur; in illius locum aliquando ſubſtituitur *ex plumbo vitrum*, quod a verâ gemmâ pondere et duritie facile diſtinguitur; mollius enim et gravius verâ gemmâ.

[*n*] Merret's Notes on Neri, chap. 82. Claveus ſaw *Silver* calcined two months in a glaſs furnace; the twelfth part of which became a *citron glaſs*.

[*o*] Shaw's Abridg. of Boyle, vol. i. p. 458. To ſhew more particularly that glaſs is porous, we took *ſilver* calcined by burning *ſulphur* on it in the open air, and laid it upon a piece of *glaſs*, and placed it with the pigment uppermoſt, upon a few

4. Having carefully purified an ounce of *Silver*, I kept it in fusion some hours, with a small quantity of *glass*, and found, that the glass, when cold, had formed a beautiful *yellow enamel* on the surface of the *silver*.
5. *Leaf silver* laid on red hot glass tinges it *yellow*.

When we meet with authors, who mention a blue or greenish colour communicated by silver, the cause must have been, that the silver used in such processes was mixed with *copper*, as it generally is, when it is not carefully purified [*p*]. I have always found, that *silver* purified by the *test* retained so much *copper*, that, when melted several times with nitre and borax, it imparted a *green tinge* at the first and second melting, though afterwards *no such colour* was obtainable from it.

quick coals to neal a while; we gave it such a heat as might make and keep it red hot, without fusion; and then suffering it to cool by degrees, we found that the *glass* had required a *yellow and almost golden colour*.

Shaw's Abridg. of Boyle, vol. ii. p. 98. I learned from one of the chief artificers in painted glass, that those of his trade colour it *yellow* with a preparation of a *calx of Silver*.

Kunkel's Art of glass, part ii. art. 49. Experiment shews that it is from *Silver* the *finest yellow* is obtained. Shaw's Lectures, p. 316. A little *Silver* tinges white *glass yellow*.

Hook's Micrographia. obs. 10. of Metalline colours. A third argument that the particles of metals are transparent is, that being calcined and melted with glass, they tinge the glass with transparent colours. Thus the *calx of silver* tinges the *glass* on which it is annealed with a *lovely yellow or gold colour*.

[*p*] Merret's Notes on Neri, c. 90. Junker, Conspect. Chem. tab. XXXIV. p. 889. 901. Shaw's Abridg. of Boyle, vol. ii. p. 98.

COPPER.

GREEN is the only colour which *copper*, the metal next to silver in *denſity*, communicates to *glaſs*, when melted with it in a ſufficient heat, *without any additional ingredient:* Thus

1. By grinding *cryſtal glaſs* in a *copper* mortar, and afterwards melting it, it becomes *green*.
2. *Copper* calcined *per ſe* in a furnace [q].
3. *Copper* calcined with ſulphur [r], and
4. Scales beaten off from red hot *copper* plates mixed with *glaſs*, equally impart a *green colour* to it.

It is indifferent in what manner the *copper* is prepared, in order to tinge the glaſs green, provided it be expoſed, *without any other ingredient*, to a ſufficient degree of heat [s]. I have frequently produced a *fine green* from *copper* filings unprepared.

[q] Shaw's Abridg. Boyle, vol.ii. p. 98. Though *copper calcined per ſe* affords but a dark and baſely-coloured calx, yet the glaſs-men tinge their glaſs *green* therewith.

Neri, chap. 92. This ſort of *pureſt glaſs* will be tinged into all colours you deſire: for example, into an *emerald* with *braſs* thrice calcined, as is done for ordinary glaſs: into a ſea *green* with *braſs* calcined to redneſs.

[r] Junker, Conſp. Chem. tab. XIX. p. 433. Beryllus marinæ *viriditatis* per *cuprum* cum ſulphure calcinatum.

[s] Kunkel's Notes on Neri, chap. 32. Though with *copper* alone one may produce *green*, it is neverthleleſs crocus martis differently prepared that makes a variety in it. I have not found that the different manners of preparing copper have produced different colours. I have experienced that by calcining *copper per ſe*, without any addition, I could produce all the effects that the author teaches us to bring about by different preparations of that metal.

If

If a quantity of *ſalts* be added in the preparation, they will, by attenuating the mixture, and conſequently *leſſening* its *ſpecific gravity*, make the glaſs incline to blue, the colour next in order [*t*]; but this happens only when the fire is moderate; for in a greater degree of heat, the redundant ſalts, even thoſe of the moſt fixed nature, are expelled [*u*].

It is true, that copper is mentioned by ſome writers, as an ingredient in *red* glaſs and enamel: but the *red*, which is the colour of the metal not diſſolved or mixed with the glaſs, remains only while the compoſition is expoſed to ſuch a degree of heat as is too ſmall to melt and incorporate it; for, if it be ſuffered to remain in the furnace *a few minutes after the copper* is added, the maſs will turn out *green* inſtead of *red* [*w*]: in effect, the preparation of *copper* recommended on this occaſion, is exactly the ſame as that uſed in tinging *glaſs green*.

[*t*] Flora Saturnizans, chap. xi. art. 6. When a green colour is to be given to glaſs, care muſt be taken *not* to uſe *too much ſalt* in the compoſition of the glaſs; otherwiſe the colour will be *blueiſh*, and bordering on the colour of the aigue marine.

Neri, chap. 32. An emerald colour in glaſs.

In making green you muſt obſerve that the metal have *not much ſalt*; with metal that hath much ſalt, as cryſtal and rochetta have, you cannot make a fair green, but only a ſea green; for the ſalt conſumes the green, and always inclines the colour to a blue; wherefore, when you would make *a fair green*, put *common metal.*

Shaw's Lectures, p. 29. Copper precipitated with common ſalt out of aqua fortis gives the torquois colour to white glaſs, when melted therewith.

[*u*] Kunkel's Remarks on Merret's Notes, p. 299.

[*w*] Neri, chap. 127. This chapter deſcribes the method of making red glaſs, in the compoſition of which copper is uſed; and

IRON.

IRON, being of all metals the moſt imperfect, is ſubject by various means, to be calcined or reduced to a ruddy crocus, ſimilar to the ruſt that ariſes from it's being corroded by the acid in the air. In this ſtate, it requires a conſiderable degree of heat to diſſolve and incorporate it with glaſs: till that heat is applied, it retains it's ruddy colour; by increaſing the heat, it paſſes through the intermediate colours, till it arrives at it's *permanent* one, which is *blue:* this being effected in the ſame degree of heat in which we have examined the other metals, that is, *the greateſt that the glaſs will bear without loſing all colour whatever.*

The green, with which the glaſs uſed for bottles and chemical veſſels is tinged, is occaſioned by the iron contained in the vegetable aſhes and ſand, of which that glaſs is compoſed. When the pots, in which the matter has been kept in fuſion, are

Kunkel makes the following remark on it: "This compoſition "is very difficult to make; it is neceſſary to ſeize the moment "at which the matter is well tinged *red*, to take it immediately "from the fire; for half a quarter of an hour too much is ſuffi-"cient to *change it's colour*." In the next chapter, ſpeaking of a *red* enamel, into the compoſition of which *copper* enters among other ingredients, Kunkel makes this remark: "This compo-"ſition is very fine, and leſs troubleſome than the preceding one: "but, after having added the *copper*, the matter muſt not be left "on the fire: if this is not attended to, *it becomes green*, and the "*red colour* that it had taken at firſt *does not laſt*."

Gellert, Chem. Metallur. problem 97. *Copper* gives a blood-red to glaſs; but if it is left too long on the fire, *it becomes green.*

nearly

nearly emptied, the glaſs remaining at the bottom is always *blue*; this is cauſed by it's continuing longeſt expoſed to the fire, and in ſo ſmall a quantity that the fire has a greater effect on it. The whole maſs acquires the *ſame colour*, if too much ſand be added in proportion to the aſhes; for, in that caſe, the materials being more difficult of fuſion, the workmen are obliged to apply a greater heat, and to continue it longer.

It is known, from the experiments of Lemery and others, that the vegetable aſhes contain iron [*x*]. To examine whether that metal be alſo contained in the ſand uſed in making this glaſs, and how far the colour of the glaſs depends upon it, I made the following experiments:

Exp. 1. Having procured ſome of the ſand uſed in making green glaſs, I melted two parts of it with one part of borax, and one part of nitre, and found that it produced a glaſs ſimilar in colour to that which is made with the ſame ſand fluxed with pot aſhes. From hence it appears, that the colouring matter was contained in the ſand.

Exp. 2. I mixed three parts of this ſand with one of powder'd charcoal, and expoſed it for ſome hours

[*x*] Becher, Phyſ. Subterran. p. 67.
Hæc prima terra (vegetabilis) cum mineralibus vitris, quæ ex arena et ſilicibus parantur, conveniens eſt, ut nulla re, niſi colore, inde diſcerni queat, qui *viridis* eſt, vel *ſubcœruleus*, indelebilem regni ſui aſteriſcum ſervans, nempe *vegetabilem viriditatem* exprimens.

Flora Sat. cap. 8. Note

As that *blue or green* colour is owing to the *iron* which is found in the aſhes of all vegetables, it muſt not be looked on as a mark capable of characteriſing a vegetable earth.

hours to a red heat. When this mixture was cold, I separated from it, by a magnet, small grains of *iron*, weighing about one twentieth part of the sand.

Exp. 3. I melted sand thus *deprived of it's iron*, with half its weight of borax and the same quantity of nitre, and found that it produced a perfectly *colourless* and transparent glass.

Exp. 4. To two parts of the white sand used in making crystal glass, and one of borax and *nitre*, I added a twentieth part in weight, of the *grains of iron*, which I had extracted from the sand by Exp. 2. and having vitrified this composition, I found that it was become exactly similar in *colour*, to that commonly used in making green glass.

Exp. 5. I exposed several pieces of *green bottle glass* made at different glass-houses, under a muffle, to a strong fire, for the space of half an hour, and found that they were all become *blue*.

If the crocus of iron is added in too great a proportion, it continues to adhere together, and remains unmixed, or at least imperfectly mixed, with the glass, retaining for that reason the colour natural to it when undissolved; or if it be in a smaller quantity, though yet in too great a proportion to be dissolved, it will make some intermediate colour between the *ruddy* and the *blue*, which last it always imparts, when in a sufficient degree of fire and a proper proportion. The necessity of a due proportion of metal to the glass has been already instanced in gold, which if in too large a proportion to be dissolved by the glass, instead

ſtead of imparting a red colour to it, runs together in it's metallic form.

Henckel has given us a method of making a *beautiful blue glaſs* by this means. It conſiſts merely in mixing *iron* with the matter of which the *pureſt glaſs* is compoſed, and expoſing it to a *violent fire*. Gellert obſerved alſo, that *iron* imparts to *glaſs* this colour [*y*]. Mr. Lehman obtained the ſame colour from emery, which is a kind of *iron ore*, or *ferruginous* ſtone, by mixing it with a vitrifiable earth; which colour he attributes to the *iron* contained in it [*z*]. Neri mentions a *ſky colour*

[*y*] Henckel, Deſert. 6. On a *blue* obtained from *iron*.

I coloured glaſs with *iron*, and gave it a *very fine blue*. I had calcined, in a pot, fileings of Styrian *ſteel*, which I kept about a quarter of an hour in the fire, without ſtirring them, till they had taken a purple colour, bordering on violet; I mixed about half a grain, which I had ground well in a glaſs mortar, with fifteen grains of very white flint and a very fine alkali; I put the whole into a crucible, covered it with care, and expoſed it *to the moſt violent fire*. The furnace being cooled, I found *a glaſs* of the colour of a *ſapphire*; it was impoſſible to ſee a finer *blue*, either for colour or tranſparence.

Gellert. Chem. Metallurg. vol. ii. prob. 97. Cobalt calcined gives to glaſs a very fine blue; but if too much cobalt, for example an eighth part, is uſed, the glaſs will become black. The calx of *iron* produces the *ſame effect*; and ſometimes it happens that one ſide of a thin piece of glaſs is of the colour of *ruſt*, while the other ſide is *blue*.

[*z*] Lehman, Treatiſe on the formation of metals, p. 37.

As to the earth of cobalt, or biſmuth, which is the baſis of the blue colour, Henckel conſidered it as a *martial earth* in his Opuſc. miner. p. 573. Some experiments which I have made render that opinion very probable. I have obtained a *very fine blue colour* from a *ferruginous Spaniſh emery*: having once pulveriſed half a pound thereof and mixed it with an equal part of black flux, I melted this mixture in a well-covered crucible in a pretty

 imparted

imparted to glaſs by Bohemian granates, which he conſtantly practiſed at a manufactory in Flanders [a]. It is well known that *iron* is the metal contained in thoſe ſtones; that they obey the loadſtone [b]; and that, being calcined with a proper heat, they yield a conſiderable quantity of iron [c].

I expoſed in a crucible to a glaſs-houſe fire, for the ſpace of thirty hours, part of a flint glaſs retort, in which a native *green vitriol of iron* had been diſtilled, and which had been corroded and tinged by it: by this means it became coloured of a *fine*

violent fire: when the matter was melted, I flung in an inflammable ſubſtance: when that had intirely ceaſed burning, I emptied the crucible, and obtained a maſs of a *moſt beautiful ſapphirine blue*; but which, as one may imagine, ſoon attracted the moiſture of the air: I repeated the experiment again without putting any black flux, and the colour became ſtill finer; but it was *remarkably beautiful* when the mixture was melted with a *vitrifiable earth*. I can attribute *this colour* only to the parts of *iron* contained in the emery.

[a] Neri, chap. 90. A curious perſon and practical chemiſt may extract a wonderful red from gold, from ſilver a *ſky colour*, and a much fairer from *granates* of Bohemia, which are low priced; for, being ſmall, you may draw a tincture from them, as I have often done in Flanders.

[b] Boyle of gems, Shaw's Abridg. vol. iii. p. 107. Suſpecting, for ſeveral reaſons, that ſome *granates* contain, beſides other metalline ſubſtances, many corpuſcles of a *ferruginous nature*, I made choice of ſome ſmall ones, which, by their deep and almoſt dark colour, I gueſſed to participate largely of *iron or ſteel*, and applied them to a vigorous loadſtone, which, as I expected, took them up: and hereto they conſtantly adhered till they were forcibly ſeparated therefrom—ibid. vol. iii. p. 120. A *chalybeate* tincture obtained from granates.

[c] Junker, tab. x. p. 273. Multi *granati* minus pellucent; atque ex his vulgares præduri, atque alioquin igne indomiti, per ignem ſolarem grandibus vitris cauſticis collectum, denique in fluorem redacti ſunt, ac *merum ferrum* præbuere.

tranſparent

tranſparent blue, not diſtinguiſhable from that which cobalt imparts to glaſs.

Iron vitrified *per ſe* is converted into a blue glaſs [*d*].

In ſhort, it is indubitable that *iron is the only metal*, which will, *without any addition*, impart to the matter of glaſs *a blue colour*; for *copper* will not communicate that colour, *without the* addition of a conſiderable quantity *of ſalts*, or ſome other matter that attenuates it; and the other metals *cannot by any means* be made to produce it at all.

Having ſhewn that the *metals* exhibit colours, invariably in the order of their *denſities*, when melted with *glaſs* in a proper proportion, *without any other ingredient*, and *expoſed to a ſufficient heat*; I ſhall proceed to ſhew that the other preparations of the metals, viz. their ſolutions, precipitates, cryſtals, &c. do for the moſt part exhibit the ſame *colours*, in the order of their *denſities*, though not ſo invariably as their glaſſes; ſome ſmall variation of colour happening in the more imperfect metals, probably from a change of denſity in their different preparations.

[*d*] Lewis's Courſe of Chem. p. 49. The ſpecific gravity of iron is to that of gold as 7,645 to 19,640. This metal requires a great degree of heat to melt it, when it throws out ſparkles, loſes conſiderably of its weight, and is at length converted into a *dark blue glaſs*.

GOLD.

GOLD precipitated from aqua regia, and washed with hot water or boiled in a solution of alcaline salt, becomes *red* on being exposed to a slight heat. Lewis, History of gold, p. 108.

2. The same *colour* is produced when this precipitate of *gold* is ground with oil of vitriol, or spirit of sulphur; or if it be mixed with sulphur, and the sulphur burnt away. Junker, tab. XXXIII. p. 859.
3. The smoaking spirit of Libavius, mixed with *gold* and afterwards drawn off from it by distillation, changes it's colour to *a blood red*.—Sol sine veste, exp. 19. Junker, tab. XXXIII. p. 861.
4. *Gold* is reduced into *a red powder*, by amalgamation with mercury, and exposing it for a considerable time to a slow heat.—Boyle's Abridg. vol. ii. p. 77. Junker, tab. XXXIX. p. 987.
5. If six parts of antimony are fused with one of *gold*, and the antimony driven off by the blast, a *red* powder of *gold* is left behind.—Cassius de Auro, cap. 10.
6. *If gold leaf* be cemented and ground with decrepitated salt, hartshorn, pumice, or chalk, and exposed to a proper heat, *the metal becomes red*, and may be precipitated from a solution of those substances in a *red* powder.—Junker, tab. XXXIII. p. 854. Lewis's History of gold, p. 74. Sol sine veste, cap. 6.

7. A *red*

7. A *red* tincture may be prepared from *gold* by several methods mentioned by Libavius, Alchem. lib. ii. p. 130. Junker, tab. XXXIII. p. 868.
8. A solution of *gold* in aqua regia prepared from sal ammoniac may be sublimed of a *blood red* colour. The same is effected by dissolving the calx, or crocus of *gold*, in other menstrua. Lewis's History of gold, p. 100. Junker, tab. XXXIII. p. 857.
9. A solution of *gold* in aqua regia, evaporated properly, affords crystals of a *bright red* colour.— Cassius de Auro, p. 109. Junker, tab. XXXIII. p. 862. 868. Lewis's History of gold, p. 99.
10. *Aurum fulminans* moistened with water, has been found to tinge gems deeply of a *fine red*. Phil. Transf. N°. 179.
11. A solution of gold tinges ivory, cotton, the skin, and other substances *red*.

Rubies being frequently found in *gold mines*, it is very probable that they receive their colour from that metal; and from this circumstance, before the experiment had been made, Libavius rightly conjectured that a solution of *gold* would communicate a *ruby* colour to *glass*. Libavii Alch. p. 88.

It does not appear that, excepting the colour natural to *gold* in its intire state, any other than *red* can be obtained from preparations of this metal: it is from this colour, which *gold* assumes whenever its metallic brightness is destroyed, that writers in chemistry call it leo *ruber* [*e*].

[*e*] Libavius de natura metallorum, lib. i. cap. 4. de auro. In suo manifesto citrinum est, in occulto summam continet *rube-*

LEAD.

THE only coloured preparation of *lead*, is that produced by calcination in the furnace. The first of the primary colours produced by this process is yellow, the calx passing from that colour through *orange* into red.

It is remarkable, that, though in the calcination previous to the reverberatory heat in which these colours are produced, the lead is *diminished in weight*; yet in the reverberatory fire it *gains* considerably, and in proportion to that *increase of gravity*, it passes from the *more refrangible* to the *less refrangible* colours; so that while the calx remains of a *less weight* than that of the *lead originally*, it's colour is *yellow*; with the *next increase of weight* it passes to *orange*, which is the colour of

dinem; unde et non tantum tinctum ipsum est, sed et tincturam *rubedinis* confert abundantem.

Dum *citrinum* dicitur, externus vultus qualis est post excoctionem respicitur: illa tamen citrinitas igne cæmenti et in opere philosophico summa *rubedine* permutatur. Itaque hinc est philosophorum axioma, quod in *citrinitate* lateat *rubedo* excellentissima, qualis est *rubedini* gemmæ.

Voces occultum, manifestum, non ita pueriliter sunt accipiendæ, quasi in superficie sit flavum, in centro *rubrum*: sed progressiones colorum in perfectione artificiali notantur, quod naturali proclivitate et dispositione post citrinitatem abolitam, assumat *rubedinem*.

Leo ruber non solet vocari, ante quam ab arte eleboratum, et astrale, ut aiunt, factum. Potentia tamen etiam simplex et naturale aurum ita vocare non est absurdum, cujus *tinctura* appellatur ejus sanguis, quo vocabulo et *fermentum rubeum* denotatur.

glaſs of lead; and when the calx is increaſed more in weight, ſo that it's gravity is become *greater* than that of the *lead originally*, it paſſes into *red*, the next colour in order.

Theſe three colours ſucceeding each other in proportion as the gravity of the metal increaſes, ſeem to prove that, in this caſe, the *greater* denſity produces the *leſs refrangible* colours: and as *orange* is the colour of this calx, when in a *middle degree of weight*, between that which is lighter and that which is heavier than the original metal, it appears that *orange* is the colour natural to *lead* when it's weight is neither much increaſed nor diminiſhed.

SILVER.

THE only preparation of *ſilver*, which is of any primary colour (except the yellow it imparts to glaſs, and other vitreous ſubſtances, as earths or ſalts) is luna cornea, which Mr. Boyle ſays is of a *fair yellow*, Shaw's Boyle, vol. i. p. 255. Phyſical Eſſays, Edinburgh, 1754, vol. i. p.310 [*f*].

[*f*] Art. 10. Remarks on chemical ſolutions and precipitations, by A. Plummet, M. D.

When either a muria of ſea ſalt, a ſolution of ſalt ammoniac, or ſpirit of ſea ſalt (for theſe three have nearly the ſame effects) is put into a *ſolution of ſilver*; it becomes milky, and, as it were, crudled, and at length a white powder ſubſides to the bottom: this powder, being waſhed with warm water and dried, is ſoft and impalpable; it's weight exceeds that of the ſilver diſſolved by

COPPER

COPPER and IRON.

IT appears then that all the preparations of *gold*, *lead*, and *ſilver*, invariably retain the *colours* peculiar to the *order* of their *denſities*, and that they are the *ſame with thoſe which they communicate to glaſs*.

The two moſt imperfect metals, copper and iron, being very eaſily acted on by almoſt all menſtrua, the colours of their ſolutions, &c. viz. green and blue, are apt to change into each other's order; the copper in ſome ſolvents becoming blue and the iron green, and in other ſolvents vice verſa; this probably depending on the increaſe or diminution of their denſities.

The ſolutions of copper, in the acids of nitre and ſea ſalt, and in the vegetable acids, are green. But if copper be attenuated, by ſolution in volatile alcalies, it becomes blue. Theophraſtus and others have obſerved, that *emeralds* are frequently found in *copper mines*; and it is probable that they obtain their tinge from that metal.

I melted ſome *emeralds* with twice their weight of ſalts, and found that they had formed a fine *geren glaſs*, ſuch as would have been produced from the ſame quantity of a *vitrifiable earth*, and about a hundredth part of its weight of *copper*.

more the one ſixth part. This powder comes much ſooner to fuſion than ſilver, but does not recover the appearance or properties of that metal; for it looks like a piece of *yellowiſh glaſs*, ſemiopaque and brittle, yet bending or yielding a little, whence it gets the name of luna cornea.

Iron

Iron diſſolved by the vitriolic acid is green; but if further attenuated by a chemical proceſs, it produces that beautiful colour called *Pruſſian blue*. Phil. Tranſ. N°. 38. Henckel, Diſſert. 6.

A ſimilar *blue* may be obtained from the *iron* contained in the aſhes of all plants. Henckel, Flor. ſat. chap. 8. parag. 55.

Having expoſed a pound of wood aſhes in a luted crucible, to a pretty ſtrong fire, for thirty hours, the greateſt part of them became tinged *blue* by the *iron* contained in them.

A *blue* may be alſo extracted from a *martial vitriol*, by ſpirit of wine. Henckel, de appropriatione, chap. 2. parag. 257.

An inſtance of a mineral ſubſtance changing it's colour from *green* to *blue* on it's *ſpecific gravity* being *diminiſhed*, appears in a ſtone deſcribed by Dr. Grew in the Muſeum of the Royal Society: this gem is a kind of *emerald*, which, when *expanded* by heat, becomes *blue*, and remains of that colour till *cold*, in which ſtate it returns to it's uſual colour, which is *green*.

Tin is not capable of being vitrified, or imparting any colour to glaſs; nor are any preparations of it of any primary colour.

MERCURY.

THERE is no body of an intermediate *weight* between *gold* and *mercury*; and it is probable that a great part of the difference between their ſpecific gravities depends on the *fluidity* of the one and the *ſolidity* of the other.

Mercury is not capable of communicating any colour to *glaſs*, being ſo volatile that it will not bear the degree of heat neceſſary to incorporate it with the glaſs in fuſion.

But it is well known that it's *calx*, either prepared *per ſe*, or by diſſolving it in an acid and evaporating the menſtruum, is *red*.

2. A ſolution of mercury tinges the ſkin, &c. *red*, as *gold* does.

PLATINA.

THE *ſpecific gravity* of *platina* being nearly equal to that of *gold*, it ſeems neceſſary to examine whether the colour of it's preparations correſpond with thoſe of gold.

On looking into a diſſertation written by Dr. Lewis on that metal, in the Philoſ. Tranſ. I find that the *precipitates* and *cryſtals* obtained from ſolutions of *platina* are *red:* and that a ſolution of that metal in aqua regia to perfect ſaturation is of a *dark red*, though, when diluted, *yellow*; in the ſame manner that "a *red* liquor (as Sir Iſaac Newton "obſerves) in a *conical glaſs*, looks of a pale and "dilute

" dilute *yellow*, at the bottom, where it is thin;
" and a little higher, where it is thicker, *orange*;
" where it is thicker ſtill, it becomes *red*; and
" where it is thickeſt, the liquor is *deepeſt and dark-*
" *eſt*." Newton's Opt. p. 160.

HAVING gone through theſe experiments and facts, which ſeem to ſhew that the *metals* invariably exhibit *colours* in the order of their *denſities*, when melted with *glaſs*, under the circumſtances above mentioned; and that the *other preparations* of the ſame metals, for the moſt part, aſſume the *ſame colours*; it ſeemed probable that the cauſe, on which the colour of natural bodies depend, may ſometimes be conjectured from the chemical analyſis of ſuch ſubſtances. This I have attempted with regard to the colour of plants.

It is known from the experiments of Lemery and others, that all earth is impregnated with *iron*; that the *ferruginous* matter is received into the roots of plants in their growth, and makes part of their ſubſtance, and is univerſally diſſeminated through them; and that *iron* may be ſeparated by a magnet from the *aſhes of all vegetables* [*g*].

It has been already obſerved, that the *green* colour of the *glaſs* uſed in making bottles, is cauſed by the *iron* contained in the materials of which it is made; and I have cited Becher's opinion, that the *green* or *blue* colour in glaſs is an indelible mark of it's *vegetable* origin.

[*g*] Lemery's Mem. de l'Academ. anno 1706.
Memoirs of the Acad. of Upſal and Stockholm, of the earth found in vegetables, by J. G. Wallerius, 1760.

This obſervation of the conſtancy of that *colour* in glaſs made of *vegetable aſhes*, and it's being cauſed by *iron*, led me to conjecture, that the *colour* of the *intire vegetables* ariſes alſo from the iron, ſo univerſally diffuſed throughout their ſubſtance in their growth.

Green is the colour which *iron* aſſumes conſtantly, when diſſolved by the *acid in the air*; that metal thus diſſolved being a true green vitriol of iron [*h*]: and as this ferruginous or vitriolic matter is univerſally diſſeminated through the leaves and branches of plants, thoſe parts of it which are at the ſurface will, by their contact with the air, aſſume the colour peculiar to its ſalt or vitriol.

Moſt vegetables, when they grow in ſuch a manner as to be defended from the contact of the air, are prevented from becoming green.

This happens to the roots of trees, and as much of their ſtem as is covered with earth: graſs growing under ſtones, or other bodies, that accidentally lie on it, is white; not having the leaſt green, but as the air has acceſs to it: and it is a method commonly uſed by gardeners, to cover with earth thoſe parts of plants which they would preſerve white: by that means hindering them from being tinged green by the contact of the air, as the parts

[*h*] Shaw's Notes to Boerhaave's Chemiſtry, vol. i. p. 94. *Iron* is eaſily diſſolved in ſalts, dew, air, &c. By the action of any of theſe it contracts a ruſt, which is nothing but the flowers of iron, or iron diſſolved, and forſaken by it's diſſolvent: for *iron* examined with a microſcope when it firſt becomes ruſty, ſhews it's ſurface covered with a number of pellucid *vitriolic lamellæ*, or glebes, which, being afterwards dried by the fluid menſtruum's evaporating, become a ruddy calx.

expofed to it are: though it appears from experiment that the prefence of light, as well as of air, is neceffary to the production of the colour of plants.

Befides the *iron* diffolved at the *furface* of plants by the air, that which is contained in the *infide* of them, may be kept in a ftate of folution, when it meets with a proper quantity of *acid;* and it is remarkable that the infide of moft fruits and other parts of plants remain *green* no longer than they continue in an *acid* ftate.

The quantity of *iron* contained in plants will not appear too fmall to produce their colour, when it is known that one grain of vitriol, of which only a fmall part is iron, the reft being acid and water, is able fenfibly to communicate a *green colour* to ten thoufand grains of water. Lemery mentions this great divifibility of iron as an argument of it's being able to pafs into the fmalleft parts of plants. Mem. Acad. anno 1706.

A circumftance which ftrongly confirms that the *colouring matter of vegetables*, and a *ferruginous vitriolic fubftance*, are of one and the fame kind, is, that the *vitriol of iron*, which is *green*, paffes through the fame colours, while it's moifture is evaporating, which *vegetables* do, when by withering they undergo the fame fort of change: the *vitriol* deprived of it's water by calcination grows firft *yellow* and then *red* [*i*]; and Sir Ifaac Newton

[*i*] Boerhaave's Chem. vol. ii. procefs 164. If this fecond calx (that is, *green vitriol* reduced to powder by a moderate heat) be calcined in a crucible, in an open ftrong fire, it grows *yellow*, *red*, and at length becomes a deep purple powder.

has

has obſerved that, " when *vegetables wither*, ſome " of them turn to a *greeniſh yellow*, and others to " a more perfect *yellow* or *orange*, or perhaps to *red*, " paſſing firſt through the aforeſaid intermediate " colours: which changes ſeem to be effected by " the exhaling of the moiſture, which may leave " the tinging corpuſcles *more denſe* and ſomething " augmented by the accretion of the oily and earthy " parts of that moiſture." Newton's Optics, lib. ii. prop. 7.

This is the only paſſage in Newton, in which he inſtances any *permanent colour* of a natural body as ariſing from a *change of denſity*: and though he has not any where at large delivered his opinion on this ſubject; it appears that, in this caſe, he conſidered the *leſs refrangible colours* in withered vegetables as ariſing from their *increaſe of denſity*; which is what I endeavoured in the beginning of this paper to prove deducible from his doctrines.

I am,

My Lord,

Your Lordſhip's

moſt obedient

and moſt humble ſervant,

Old Palace Yard,
Jan. 17, 1765.

Edward Delaval.

IV. *An*